BBC RD 1978/33

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1974
THE QUEEN'S AWARD TO INDUSTRY

REPORT

M.F. AND L.F. RECEPTION: susceptibility of domestic receivers to interference

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THE BRITISH BROADCASTING CORPORATION

December 1978

BBC RD 1978/33
UDC 621.391.82:
621.396.62

M.F. AND L.F. RECEPTION: SUSCEPTIBILITY OF DOMESTIC RECEIVERS TO INTERFERENCE

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Summary

Self-generated interference in domestic l.f. and m.f. broadcast receivers has been investigated theoretically and the susceptibility of five typical receivers has been measured. A systematic analysis of the results has been attempted and a procedure established for assisting planning exercises by assessing the likelihood of interference from particular combinations of frequencies.

Issued under the authority of

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

December 1978
(RA-177)

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SUSCEPTIBILITY OF DOMESTIC RECEIVERS TO INTERFERENCE

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M.F. AND L.F. RECEPTION:
SUSCEPTIBILITY OF DOMESTIC RECEIVERS TO INTERFERENCE

R.V. Harvey, B.Sc., M.I.E,E.

1. Introduction

A successful frequency assignment plan for l.f. and m.f. broadcasting will have arranged that co-channel and adjacent-channel interference are nowhere excessive. But a plan must also avoid other frequency assignments that cause interference to be generated in the broadcast receivers themselves.

Self-generated interference may arise in the receiver in many different ways. Its effect on planning can be forecast, to some extent, from a knowledge of the mechanisms by which interference may be produced and the channel frequencies which could be affected. But the precise extent and likelihood of interference depends on factors which must be measured in the laboratory.

2. Receivers tested

A representative selection of five l.f./m.f. portable receivers in production in 1974 was examined. All the receivers had ferrite-rod aerials for l.f. and m.f. reception. The prices ranged from about £10 to £28. Car radios were not tested, but it was thought that their behaviour would be adequately represented by that of the five portables.

3. Test equipment

Each receiver was placed in a screened enclosure (see Fig. 1) and subjected to a known field. The construction and calibration of this 'signal injector' is fully described elsewhere.[1] Briefly, the signal was applied to the sides of an axial slot in a rectangular cylinder inside a screened enclosure; this produced a uniform, known field parallel to the ferrite rod aerial of the receiver under test. Fig. 2 shows a simplified diagram of the arrangement.

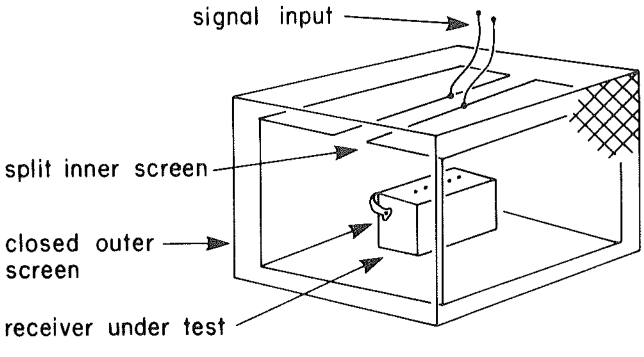

Fig. 1 - Test enclosure

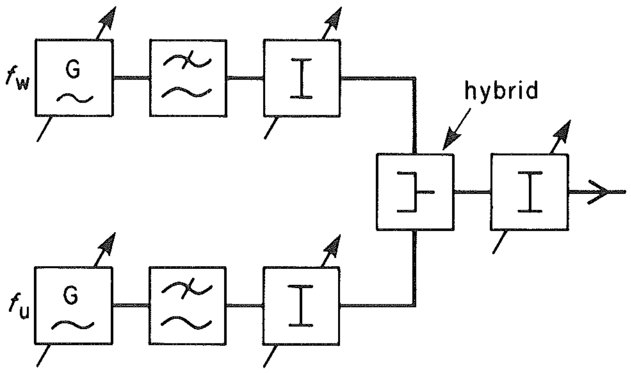

Fig. 2 - Combination of test signals

When two or more signals were applied together the signal sources were isolated from each other by hybrid transformers and suitably filtered to remove harmonics that would otherwise have falsified the measurements. (See Fig. 2.)

4. Interference mechanisms

Table 1 shows a list of 11 different types of interference-producing mechanisms starting with those that are the simplest and most likely to give trouble. The list may not be complete but is believed to be adequate. In all cases, the interference consists mainly of an audible whistle or beat. The beat frequency depends on one or more of the radio frequencies involved; these are the frequencies of the wanted (f_w) and unwanted (f_u) signals, the intermediate frequency (f_i) and the 'tuning' of the local-oscillator frequency ($f_o = f_w + f_i$). The beat frequency is zero for the condition given in Table 1 and for precise tuning but it may depart from zero frequency if there is a change in tuning or in the interfering signal frequency. The dependence of the beat frequency (f_b) on the tuning (f_o), the wanted signal frequency (f_w) or the unwanted signal frequency (f_u) is given by the partial derivatives shown in Table 1 for each mechanism, and is discussed in an Appendix, Section 11.

As can be seen from Table 1, the mechanisms A and B produce interference from the wanted

TABLE 1

Interference mechanisms

Note:
f_w = wanted frequency
f_u = unwanted frequency
f_v = unwanted frequency
f_o = local oscillator frequency
$f_i = f_o - f_w$ = intermediate frequency
f_b = beat frequency

Symbol	Mechanism	Values of n	Condition for zero beat and beat frequency f_b	$\frac{\partial f_b}{\partial f_o}$ F_o	$\frac{\partial f_b}{\partial f_u}$ F_u	$\frac{\partial f_b}{\partial f_w}$ F_w
A_n	i.f. harmonic feedback into r.f. amplifier	2,3	$f_w = nf_i$ $f_b = nf_o - (n+1)f_w$	n	–	–(n + 1)
B_n	r.f. harmonic feed forward into i.f. amplifier	2,3	$nf_w = f_i$ $f_b = f_o - (n + 1)f_w$	1	–	–(n + 1)
C	f_u at 'image' frequency		$f_u = f_w + 2f_i$ $f_b = 2f_o - f_u - f_w$	2	–1	–1
$D_n^{\pm}$	f_u at $\pm f_i$ from nth harmonic of f_o	2,3	$f_u = nf_o \pm f_i$ $f_b = (1 \pm n)f_o \mp f_u - f_w$	1 ± n	∓1	–1
E_n	nth harmonic of f_u at f_w	2–10	$f_w = nf_u$ $f_b = nf_u - f_w$	0	n	–1
F_n	nth harmonic of f_u at image	2–16	$nf_u = f_w + 2f_i$ $f_b = 2f_o - nf_u - f_w$	2	–n	–1
G±	f_u and f_w have sum or difference at f_i	–	$f_u \pm f_w = \pm f_i$ $f_b = f_o \mp f_u - 2f_w$	1	∓1	–1 ± 1
H±	f_u and f_v have sum or difference at f_i	–	$f_u \pm f_v = f_i$ $f_b = f_o \mp (f_u \pm f_v) - f_w$	1	∓1, ±1	–1
I±	f_u and f_v have sum or difference at f_w	–	$f_u \pm f_v = \pm f_w$ $f_b = \mp(f_u \pm f_v) - f_w$	0	±1, ∓1	–1
J±	f_u and f_v have sum or difference at image	–	$f_u \pm f_v = \pm(f_o + f_i)$ $f_b = 2f_o \mp (f_u \pm f_v) - f_w$	2	∓1, ±1	–1
K	second harmonics of f_u and f_w differ by f_i ('repeat spot')	–	$2f_u = 2f_w + f_i$ $f_b = f_o - 2f_u + f_w$	1	–2	1

signal itself; mechanisms E and I produce interference which is independent of receiver tuning. Apart from E and I, the frequencies affected by the remaining nine mechanisms depend on the value of the intermediate frequency which is fixed by the receiver manufacturer. It is important to consider:

(a) The sensitivity of typical l.f. and m.f. broadcast receivers to each of the interference mechanisms.

(b) The range of typical intermediate frequencies of broadcast receivers.

(c) The degree of mistuning which must be accepted in practice.

Table 2A shows the frequency range of the l.f. and m.f. bands in which the wanted and interfering signals must be considered. From November 1978 carrier frequencies within the m.f. band (but not the l.f. band) will be confined to multiples of

TABLE 2A

Band limits

Band	Frequency limits, kHz	
LF	150	285
MF (Pre Nov. '78)	525	1605
MF (Nov. '78)	526·5	1606·5*

TABLE 2B

Channel frequencies (ITU Regions 1 & 3)
(from 23rd November 1978)

Band	Formula	Range of integers	Channel frequencies kHz	Number of channels
LF	9L + 2	L = 17 . . . 31	155 . . . 281	15
MF	9M	M = 59 . . . 178	531 . . . 1602	120

* These limits are proposed by a number of Administrations for formal agreement at the World Administration Radio Conference 1979, but until such agreement they should only be regarded as a practical indication of effective limits based on ±4·5 kHz occupancy relative to the carrier frequencies assigned in the 1975 Geneva Plan.

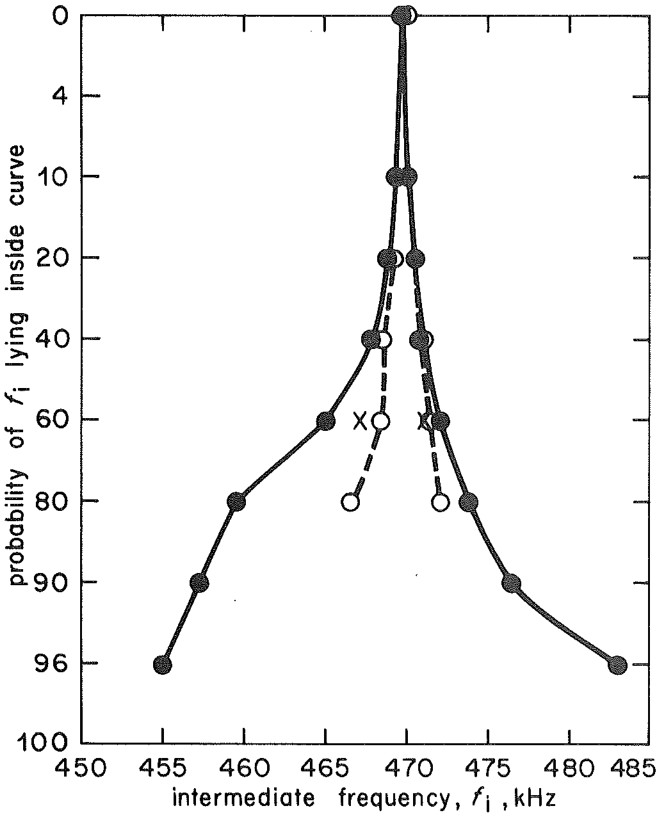

Fig. 3 - Probability distribution of intermediate frequency of domestic l.f./m.f. receivers

● 123 receivers in 1964 ○ — — 10 receivers in 1972

X 5 receivers in 1974

9 kHz. At l.f. the extreme assignments are at 155 and 281 kHz as shown in Table 2B.

5. The range of intermediate frequencies

The intermediate frequencies of 123 domestic receivers were measured in 1964. Similar tests on ten receivers were made in 1972. A probability density curve for these two sets of measurements is shown in Fig. 3 together with that of the receivers used in the tests described in Section 6.

Fig. 3 shows that the most common value of f_i is close to 470 kHz but that there is a distinct bulge on the 1964 distribution owing to a minority favouring 455 kHz. As the later curves suggest this value of f_i, which is common in the USA, is becoming less common in Europe. But, unless the BBC ceases to use a frequency of 908 or 909 kHz, the 1 to 2 kHz whistle caused by feedback of the second harmonic of f_i (mechanism A2) will impair reception by receivers having f_i = 455 kHz, particularly in fringe areas.

6. Test results

6.1. At a standard signal level

Not all the interference mechanisms given in Table 1 were found to cause interference in prac-

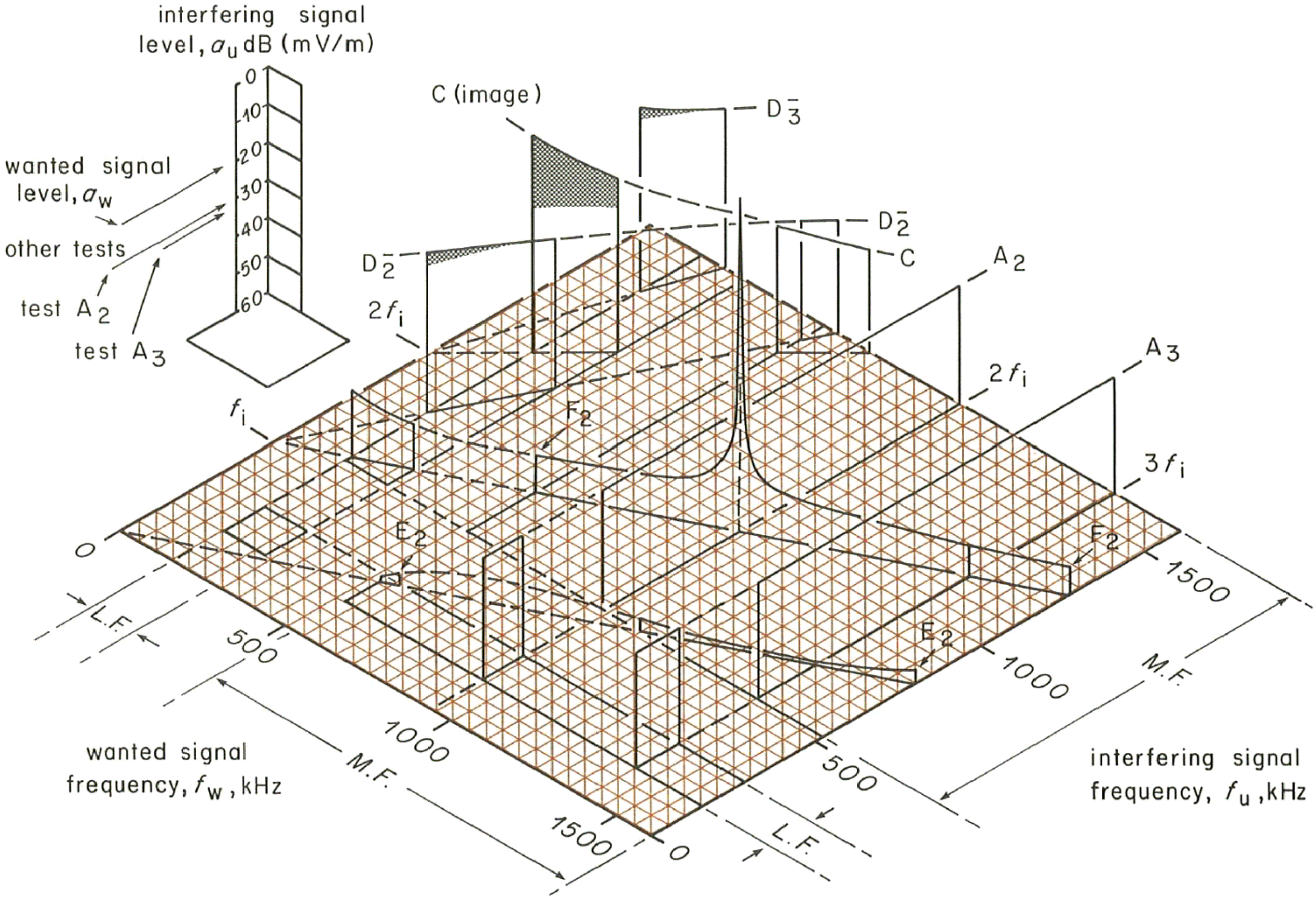

Fig. 4 - Interference susceptibility profiles for five domestic receivers. Profile letter-codes refer to seven mechanisms given in Table 1. Interference equivalent to a 1% modulation of the wanted signal. Wanted signal level 10 mV/m for all tests except A_2 and A_3. Vertical scale indicates level of interfering carrier. Shaded area indicates interference from a carrier of lower level than the wanted signal. Note that, when f_u approaches f_w, the interference is given more accurately by Figs. 5 and 12

tice. The combinations of signal frequencies that gave rise to interference are shown in the isometric diagram of Fig. 4. The f_w and f_u scales lie in the directions usually taken for the x and y axes respectively. The z co-ordinate shows, for each of the principal mechanisms, the level of the interfering signal which would cause interference judged by a particular criterion discussed below. For all except mechanism A, the wanted signal level was 10 mV/m. For mechanism A the wanted signal provided its own interference when it fell below the levels shown.

The interference criterion adopted for Fig. 4 was simple; excepting mechanism A, the level of the interfering signal was the lowest value that gave an interference beat equivalent to at least 1% modulation of a 10 mV/m wanted signal in only two of the five receivers that were examined. Putting it another way, the worst receiver was disregarded at each frequency for each mechanism and the curves given in Fig. 4 correspond to the worst of the remaining four receivers. The test frequencies were chosen carefully so that there was no doubt about the correct mechanism.*

Two mechanisms, G and H, produce a resultant at f_i as a second-order sum or difference. There were both detected but do not appear in Fig. 4 for the following reasons. For mechanism G, the interference criterion was reached at an unwanted signal level of +66 dB(mV/m) or 2 V/m; the wanted signal level was immaterial (see Section 7). For mechanism H, the interference criterion was reached when the two interfering signals (differing by f_i) reached a level of +50 dB above that of the wanted signal. This test was difficult to engineer for all appropriate combinations of frequency but the result appeared to be largely independent of these.

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* The measurements were performed by R.J.J. Roach.

During the latter tests it was suspected that in conditions of high field strength at two frequencies separated by f_i, the test apparatus (or indeed the surroundings in a practical situation – drain-pipes, rusty wires etc.) may generate the signal at f_i. Accordingly, a supplementary test was made of the direct i.f. breakthrough of the receivers. It was found that an ambient field strength at f_i was just acceptable at a level of −10 dB with reference to that of the tuned wanted signal. There is thus some doubt as to the results for mechanism H which may become important when transmitters differing by f_i are co-sited.

6.2. At other signal levels

As the main tests were conducted at a fixed level of the wanted signal, it was necessary to show how to find the interfering signal levels that would give the same interference at other wanted signal levels. This extrapolation was shown to be possible by first approximating to a theoretical model of the system and then making a few objective tests to confirm the validity of the model. This theory and its confirmation are described in an Appendix, Section 11 and summarized in Section 7.3 and Table 3.

As it turns out, the values of the integers F_w and F_u given in Table 1 may be taken not only as the factors relating a change in the signal or interference frequency f_w or f_u to the consequent change in beat frequency f_b but also as the factors relating a change in either signal level to that of the resultant interference. The generality of this conclusion is not guaranteed for all circumstances, but, as shown in the Appendix, it appears to suffice for this exercise. There is an exception to this generalisation for mechanism A, in which the non-linearity is strongly affected by the a.g.c. of the receiver. Nevertheless, the conclusion is helpful in forming a useful interpretation of the results as is discussed in Section 7.

7. Interpretation of results

7.1. Protection ratio

So far, the results give the interfering signal level for a particular objective criterion discussed in Section 6.1. The subjective impairment depends on the beat frequency f_b. If the interference is caused by a co-channel transmission, separated from the wanted transmission by f_b, then the relative protection ratio will depend on f_b in the way shown in Fig. 5.* The curve shown in Fig. 5 is appropriate to the normal m.f. practice of using fairly high audio compression and an audio bandwidth extending up to 10 kHz. The effect of restricting the bandwidth of the interfering modulation is shown by the dashed part of the curve in Fig. 5 and is discussed in Section 8.3. A scale of absolute signal-to-interference ratio is also given in Fig. 5, showing a basic co-channel protection of 30 dB in accordance with usual practice for m.f. planning. In the objective tests described here, a standard condition of 40 dB carrier-to-interference ratio was adopted. The test condition therefore corresponds with the most stringent condition considered acceptable for planning where the beat frequency whistle f_b is most annoying at about 2 kHz. The next step is to find the worst value of f_b in a practical interference situation.

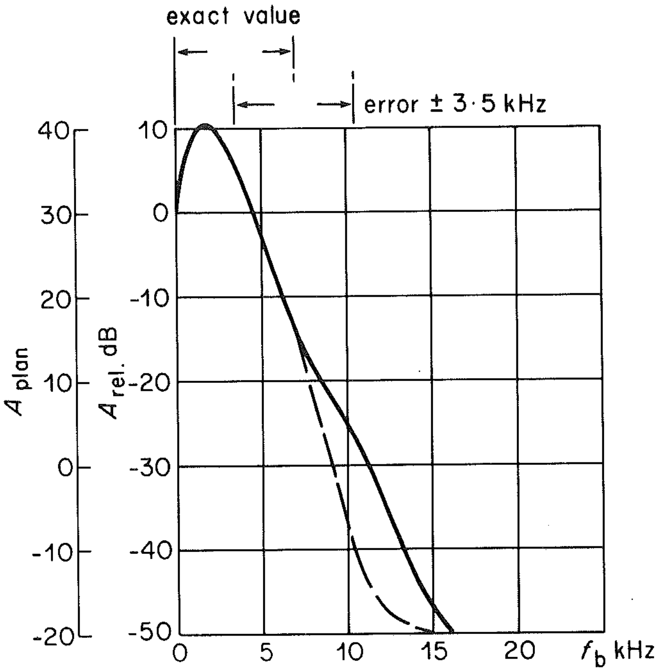

Fig. 5 - Protection ratio: A rel. = CCIR Rec. 449-2 curve B, A plan = acceptable wanted-to-unwanted carrier ratio at a beat frequency f_b, showing an example of f_b = 7 kHz ± 3·5 kHz for errors in f_i and f_o. The dashed curve applies when modulation bandwidths are restricted to 4·5 kHz (curve D of CCIR Rec. 449-2)

7.2. Practical frequency tolerances

If, from a study of Fig. 4, a particular combination of frequencies seems likely to produce interference, then the beat frequency f_b may be calculated from Table 1 assuming that the receiver is correctly tuned so that $f_o = f_i + f_w$ exactly. However, a range of values of f_i must be considered according to the probability distribution of Fig. 3. For practical purposes, we shall consider only the 80% of receivers existing in 1972 and having values of f_i lying between ±2·5 kHz of 469·5 kHz as shown in Fig. 3. In addition, we shall allow a tuning error in f_o of ±1 kHz and we shall make the pessimistic assumption that the mis-tuning is always in the worst direction. The combined effect of these tolerances is that f_o is within ±3·5 kHz of the frequency that would make $f_o - f_w = f_i = 469{\cdot}5$ kHz.

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* CCIR Recommendation 449-2 for l.f. and m.f. a.m. transmissions with a high degree of compression.

The value of f_b may be calculated from the expression given in Table 1 for a particular mechanism and for particular values of f_w and f_u. To this exact value of f_b a maximum error must be added which is $\pm 3{\cdot}5F_o$ kHz where F_o is the partial derivative $\partial f_b / \partial f_o$ as given in Table 1 and discussed in Section 6: an example of the extent of this error is shown in Fig. 5. The pertinent calculations are given in Table 3 for ten mechanisms.

Table 3 gives the beat frequency f_b and its tolerance for each mechanism. Because of the 2 kHz offset of the planned l.f. band channels, the value of f_b depends on whether the wanted and interfering signals are in the same or different bands. The Table also gives the differential coefficients governing the beat frequency and amplitude; the derivation of these is explained in the Appendix, Section 11 and their use in constructing the graphs, Figs. 6 – 11, is explained in the next section.

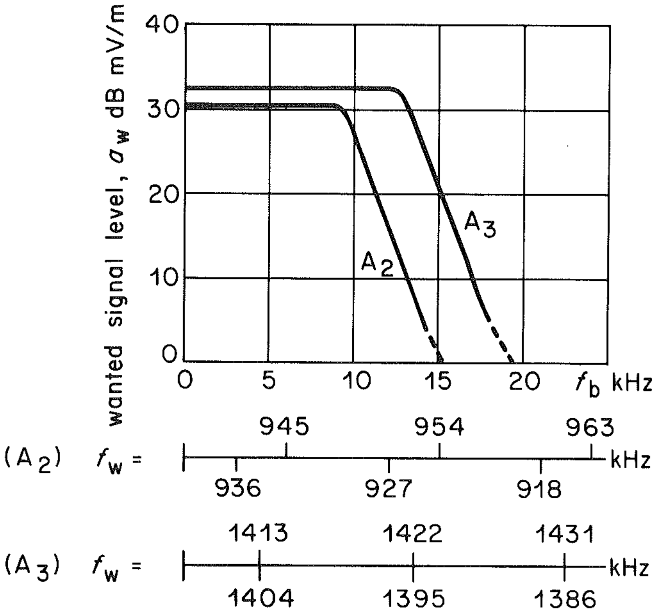

Fig. 6 - *Mechanism A: minimum wanted signal level: dependence on wanted channel frequency*

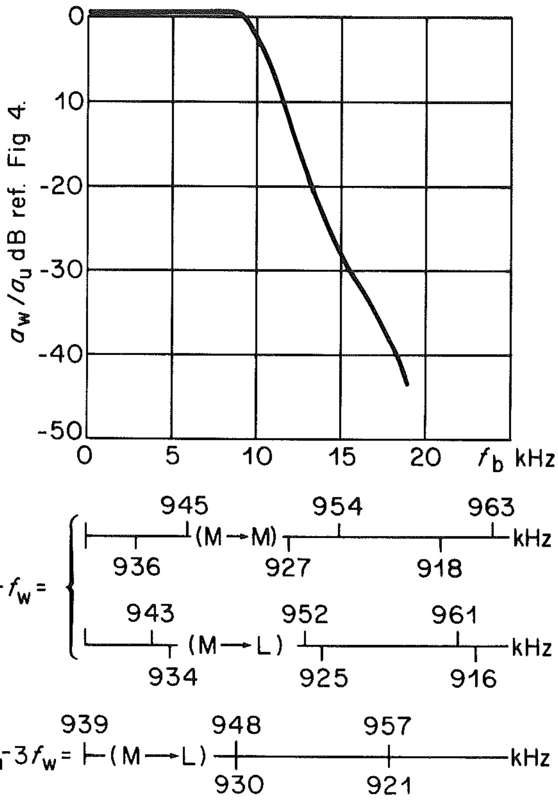

Fig. 7 - Mechanisms C and D_3^-: acceptable wanted/unwanted signal level ratio relative to that given by Fig. 4

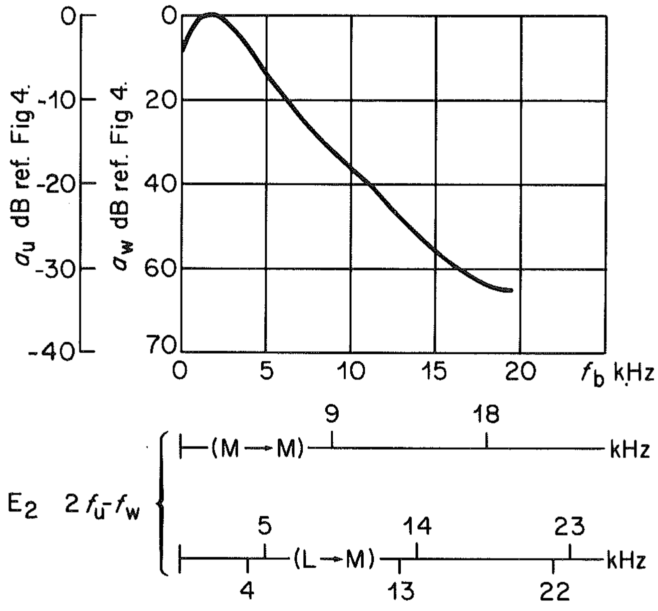

Fig. 8 - Mechanism E_2: acceptable levels of unwanted (a_u) and wanted (a_w) signals relative to those given by Fig. 4

TABLE 3

Interference mechanism	Differential coefficients Frequency				Amplitude [1]		Interfering/ interfered bands [2]	Beat frequency f_b kHz			Graph Fig. No.
	F_o	F_u	F_w	F_{wo}	A_u	A_w		[3] general expression	[4] for nearest channels	[5] max. error	
A_2	2		−3	−1		−1(1)	M/M	$f_w - 2f_i$	−3 ± 9	± 7	6
A_3	3		−4	−1		−1(2)	M/M	$f_w - 3f_i$	4·5 ± 9	±10·5	6
C	2	−1	−1	1	1	−1	M/M	$f_u - f_w - 2f_i$	−3 ± 9	± 7	7
							M/L	$f_u - f_w - 2f_i$	+4 ± 9	± 7	7
D_2^-	−1	1	−1	−2	1	−1	M/M	$f_u - 2f_w - f_i$	−1·5 ± 9	± 3·5	10
							M/L	$f_u - 2f_w - f_i$	+3·5 ± 9	± 3·5	10
D_3^-	−2	1	−1	−3	1	−1	M/L	$f_u - 3f_w - 2f_i$	0 ± 9	± 7	7
E_2	0	2	−1	−1	2	−1	M/M	$2f_u - f_w$	0 ± 9	0	8
							L/M	$2f_u - f_w$	−4 ± 9	0	8
F_2	2	−2	−1	1	2	−1	M/M	$2f_u - f_w - 2f_i$	−3 ± 9	± 7	9
							M/L	$2f_u - f_w - 2f_i$	+4 ± 9	± 7	9
H^-	1	±1	−1	0	1	−1	M/M	$f_u - f_v - f_i$	−1·5 ± 9	± 3·5	10
							M/L	$f_u - f_v - f_i$	+3·5 ± 9	± 3·5	10
[6] G^-	1	−1	−2	−1	1	0	M/M	$-f_u + f_w - f_i$	−1·5 ± 9	± 3·5	10
							M/L	$-f_u + f_w - f_i$	+3·5 ± 9	± 3·5	10
K	1	−2	1	2	2	1	M/M	$2f_u - 2f_w - f_i$	−1·5 ± 18	± 3·5	11

NOTES:

[1] The coefficients A_w for mechanism A are shown in brackets for a receiver without a.g.c.

[2] The letter M refers to the m.f. band where channel frequencies are 9M kHz and L refers to the l.f. band where channel frequencies are 9L + 2 kHz (from Nov. 1978).

[3] The value of f_i is taken as 469·5 kHz.

[4] With exact tuning and channelling, only these values are possible.

[5] The error in f_b arises from ±1 kHz tuning error ±2·5 kHz spread in f_i leading to a maximum error of $\pm 3{\cdot}5F_o$ kHz.

[6] Mechanisms G and K are included here for variety though they did not give rise to significant interference during the tests.

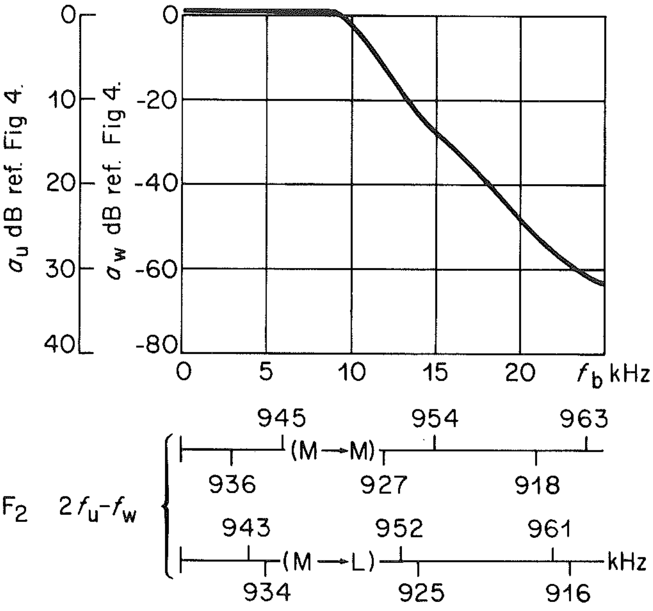

Fig. 9 - Mechanism F_2: acceptable levels of unwanted (a_u) and wanted (a_w) signals relative to those given by Fig. 4

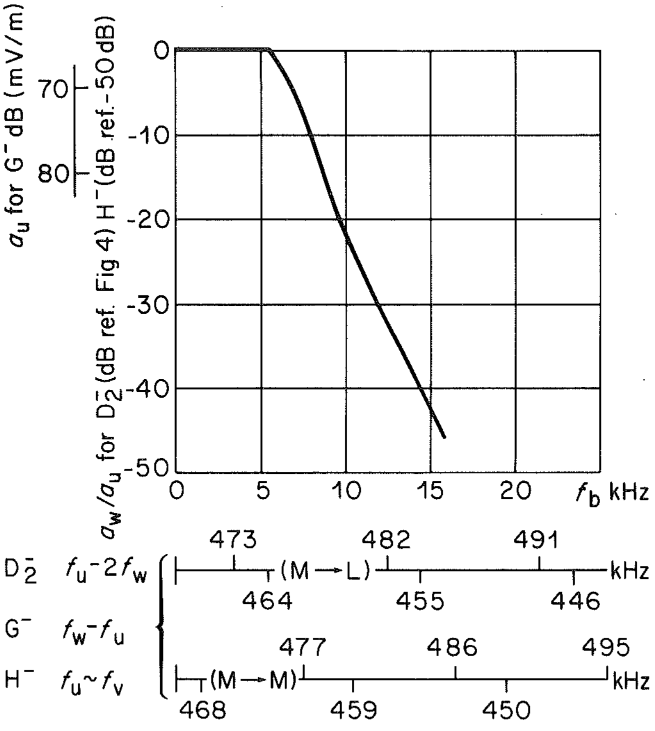

Fig. 10 - Mechanisms D_2^- G^- and H^-: acceptable wanted/unwanted signal ratio relative to that given by Fig. 4. Reference for H^- is −50 dB (see Section 6.1)

7.3. Derivation and use of graphs

Figs. 6 to 11 show how, for an acceptable interference for planning purposes, the permissible signal levels are related to the beat frequency.

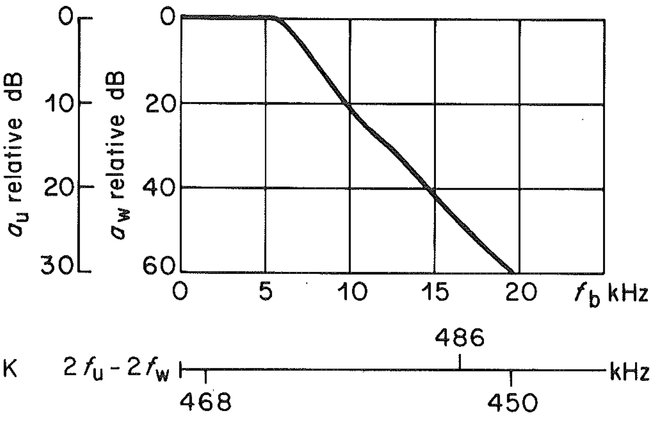

Fig. 11 - Mechanism K: acceptable levels of wanted and unwanted signals relative to reference datum

Also shown on the beat-frequency scales are those frequencies that arise from the proposed 9 kHz channelling, so that the effect of a change of one or two channels may be assessed. Thus, the effect on f_b of changing the wanted or the interfering frequency by one channel is given by F_{wo} or F_u respectively, (see Table 3). In nearly all cases, one of these two coefficients has a modulus of unity, so that the frequency scales all have 9 kHz steps. Where F_{wo} and F_u are greater as in mechanism K, the steps are correspondingly greater. However, in addition to the 9 kHz steps, there is in most cases an offset from zero beat even for the nearest channel. This offset arises from two sources; first, the mean value of f_i is not a multiple of 9 kHz but is, in kHz

$$469{\cdot}5 = (9 \times 52) + 1{\cdot}5$$

Second, channel frequencies in the two bands are given by

$$9L + 2 \text{ kHz at LF}$$
$$9M + 0 \text{ kHz at MF}$$

leading to a basic 2 kHz beat (multiplied by the appropriate coefficients) whenever the wanted and interfering carriers are in different frequency bands. As Table 3 shows, this 'other-band' interference occurs in nearly half the total significant mechanisms.

The shape of the graphs may be understood by considering the protection ratio curve of Fig. 5 to be convoluted with the maximum frequency error given in Table 3. This convolution has the effect of 'blurring' the curve, broadening the skirts of the curve and filling in the dimple at zero offset. Two of the graphs serve more than one mechanism because the coefficients are the same. For example, Fig. 7 covers mechanisms D and D_3^- because coefficients F_o, F_u, F_w, A_u and A_w have moduli which are the same for the two mechanisms. An exception is $F_{wo} = -3$ for D_3^-, indicating that in this case a change of one channel in the m.f. interfering signal will cause a change of 27 kHz in the whistle on the wanted l.f. signal. The ordinate scale in Fig. 7 refers to the wanted-to-interfering signal ratio a_w/a_u, taking as the reference the value given by Fig. 4 for the particular mechanism and frequencies concerned.

Thus, to take a bad case of image-channel interference from

$$f_u = 1152 \text{ kHz to } f_w = 200 \text{ kHz}$$

Fig. 4 shows that this involves mechanism C and the objective reference for signal levels is

$$a_u = 10 \text{ dB mV/m}, a_w = 20 \text{ dB mV/m}$$

Turning to Fig. 7 and noting that, against (C), we must put $f_u - f_w = 952$, we read off a worst-case beat frequency of $f_b = 13$ kHz and an ordinate of $a_w/a_u = -18$ dB, ref. Fig. 4. This means that the interference will be acceptable provided that the absolute signal-to-interference ratio is no worse than 18 dB below the reference condition $a_w/a_u = 10$ dB, or -8 dB in this case.

Taking this latter example a little further, let us suppose that the acceptable minimum signal-to-interference ratio of -8 dB cannot be obtained for an adequate number of listeners in the area served by $f_w = 200$ kHz. Let us also suppose that there is a negotiable option on the choice of a frequency $f_w = 1125$ kHz. Fig. 7 shows immediately that this option offers an easement of 5 dB (from -18 dB to -23 dB) in the acceptable signal-to-interference ratio if the frequency f_w is reduced from 1152 kHz to 1125 kHz (3 channels). This observation is clearly of value in assessing the benefit of exercising this particular option in the choice of frequencies for overlapping service areas.

Turning to another example, consider interference from

$$f_u = 774 \text{ kHz to } f_w = 1548 \text{ kHz}$$

Fig. 4 shows that mechanism E_2 is involved and that the crucial signal levels are

$$a_u = 57 \text{ dB mV/m and } a_w = 20 \text{ dB mV/m.}$$

Table 3 refers to Fig. 8 and shows that, for mechanism E_2, the value of F_o is zero. This means that frequency errors in the receiver have no effect on f_b and there is therefore no blurring of the shape of the graph in Fig. 8. In the present example, the value of the abscissa is

$$2f_u - f_w = f_b = 0$$

The ordinate has two scales because, although the interference depends linearly on the wanted signal level ($A_w = -1$), it has a square-law response to the interfering signal level ($A_u = 2$) since it is a second-harmonic mechanism. Thus, for this example where $f_b = 0$, Fig. 8 shows that the acceptable signal levels differ from the reference levels from Fig. 4, given above, as follows. Either the wanted signal level may be reduced by 10 dB or the unwanted signal level may be increased by 5 dB. In order to arrive at an acceptable compromise between the two levels, further adjustments may be made, provided that these are (in dB) in the ratios shown by A_w and A_u.

The same care in interpretation of the ordinate scales is required for Figs. 8, 9 and 11 for the reasons given above.

In Fig. 10, three mechanisms are treated but only D_2^- is given as a specific mechanism in Fig. 4. Of the other two mechanisms, G^- required a level which was below the reference plane of Fig. 4 and was therefore insignificant, but is of interest since $A_w = 0$ meaning that the interference level is independent of that of the wanted signal. Mechanism H^- has significance in practice, as described in Section 6.1 but, since it involves two interfering signals, the reference has no location in the diagram of Fig. 4.

Mechanism A (Fig. 6) involves no separate interfering signal, so that the ordinate may be scaled directly in dB(mV/m) with respect to that shown in Fig. 4.

8. Discussion

8.1. Frequency planning and current receiver design

The data provided in Figs. 6 – 11 may be used in a number of ways; the procedure may be followed to check particular conjunctions of f_w and f_u, or, starting from an agreed set of values of f_w and a_w, to prepare maps showing the permissible boundaries of f_u and a_u. It would be a comparatively simple matter to prepare a program for a calculator for checking possible clashes, using an approximation to the CCIR protection-ratio curve of Fig. 5; such an approximation is given in an Appendix, Section 12, Fig. 12.

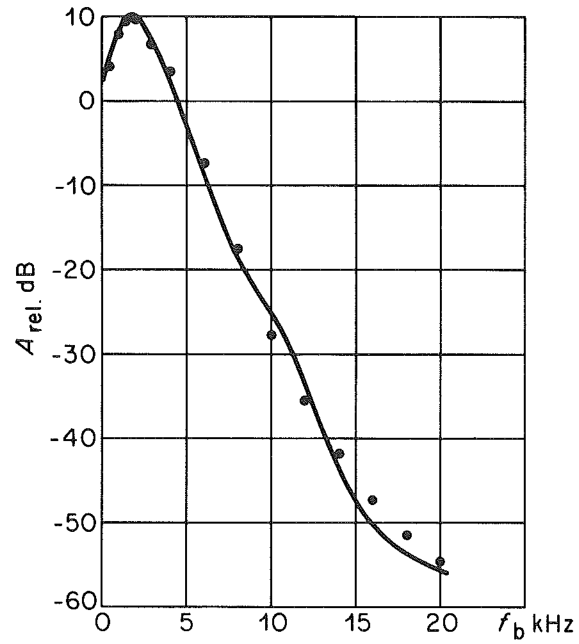

Fig. 12

———— CCIR Rec. 449-2 Curve B

•••••••• $A_{\text{rel}} = -70[1 - \exp(-f_b/3)]\,[1 - 1{\cdot}6\exp(-f_b/10)]$

The unification of 9 kHz channelling in the l.f. and m.f. bands, starting in November 1978, will alleviate some of the present problems in co-channel and adjacent channel interference but will do little to reduce self-generated interference with current receivers, owing to the intrinsic spread of intermediate frequencies and the necessary tuning tolerance. The latter features may be improved in future designs.

8.2. Possible future receiver design

The establishing of a unified 9 kHz channelling plan makes certain advances in receiver design more attractive. First the tunable local oscillator may be replaced by a simple synthesiser giving selectable outputs 9 kHz apart. Second, the i.f. amplifier may be more accurately centred on a frequency of 468 kHz, which is a harmonic of 9 kHz. In this way the self-generated interferences arising from unwanted signals in the same band would be constrained to values of f_b of 0 and 9 kHz with a tolerance of say 20 Hz. The improvement would be equivalent to an increase of 10 dB in the wanted signal level in all these cases.

Unfortunately, the l.f. channels are offset by 2 kHz from a regular 9 kHz harmonic scale. Hence the use of an accurate synthesiser will not automatically give the same improvement for interference from one band to the other, but will tend to cause interference having the most audible beat-frequency of 2 kHz. However, there may be a more suitable compromise solution which may be appreciated by an examination of Table 3. This shows that for same-band interference, denoted M/M, the offsets are multiples of the 1·5 kHz offset in f_i; these would vanish if f_o were an exact harmonic of 9 kHz and f_i were 468 kHz. But the 'other-band' cases, denoted M/L and L/M, show one offset of zero for mechanism D_3^- (made up of 3 x 2 kHz + 2 x 1·5 kHz − 9 kHz) and other offsets with a minimum value of 3·5 kHz which is 5 dB better than at 2 kHz. The only case of L/M interference gives 4 kHz offset interference independently of f_i and f_o; this involves mechanism E_2 and affects only three or four channels in each band.

It therefore seems worth considering a somewhat more complex arrangement for an optimum design in which the i.f. amplifier is slightly detuned for l.f. reception. Using the channel numbers L and M as in Table 2B, the two regimes might be as shown in Table 4.

TABLE 4

Band	f_i kHz	f_o kHz
MF	468	9(M+52)
LF	469·5	9(L+52)+3·5

The reduction of possible impairment gained by i.f. switching is probably well worth the extra receiving cost. No extra cost will be incurred for the synthesiser since the new frequency plan requires a switched 2 kHz offset in any case, even if the value of f_i remains unswitched.

An additional benefit of i.f. switching will be that l.f. to m.f. local-oscillator interference will be less annoying, since the most likely whistle will be increased in frequency from 2 kHz to 3·5 kHz.

8.3. Modulation bandwidth restriction

The curve of protection ratio, shown in Fig. 5 and chosen as the basis of the interference calculations, may lead to a pessimistic forecast in some cases since it applies only when both the wanted and interfering signal modulation extend to 10 kHz. In fact, there is increasing use of modulation filters which, in restricting the modulation spectrum to less than 10 kHz, will therefore tend to reduce adjacent-channel interference. For example, if transmitted modulation frequencies above about 4·5 kHz are removed by a filter, as is incorporated in some transmitters in the UK, the effect on the protection required by transmissions in an adjacent-channel will be as shown by the dashed line in Fig. 5. As the dashed line shows, the required protection would be reduced by up to 12 dB in certain cases. However, while this possible amelioration of interference should be borne in mind for the future it is as well to err on the safe side for the present.

9. Conclusions

Self-generated interference in a number of l.f. and m.f. receivers has been measured and a planning procedure has been established by which the frequencies and field-strengths of wanted and interfering carriers which would cause interference may be assessed.

10. Reference

1. REED, C.G.R. 1969. A signal injector for l.f. and m.f. receivers with ferrite-rod aerials. BBC Research Department Report No. 1969/41.

11. Appendix I

An analysis of the effects of changes in signal levels and frequencies

11.1. The notion of partial frequency and amplitude coefficients

We shall regard the receiver as responding primarily to the modulation of a signal at the intermediate frequency f_i. The signal at f_i is derived in the mixer from a wanted transmission at a frequency f_w by simple intermodulation with a tunable local oscillator at a frequency f_o such that $f_i = f_o - f_w$. In addition to this wanted response, and independently of the simple intermodulation with f_o, one of many other intermodulation processes may generate an unwanted signal at $f_i \pm f_b$. This interfering signal may be generated from an unwanted carrier at f_u, the local oscillator at f_o, the wanted carrier at f_w and their harmonics by a variety of mechanisms, some of which are given in Table 1. As the frequency or amplitude of the various ingredients changes, the frequency or amplitude of the resultant interference at f_b will also change in a direction or magnitude which depends on the particular mechanism involved.

It is fairly easy to find the relationship between changes in the frequencies f_o, f_w, f_u and that of the resultant f_b simply by inspection of the expressions for f_b given in Table 1. For clarity, these relationships may be separated as a set of partial differential coefficients of the form

$$\frac{\partial f_b}{\partial f_o} = F_o \qquad \frac{\partial f_b}{\partial f_u} = F_u \qquad \frac{\partial f_b}{\partial f_w} = F_w$$

These numbers describe the effect on f_b of an error in tuning by F_o, a change in the interfering frequency by F_u and a change in the wanted frequency by $F_w + F_o = F_{wo}$. (The last expression, $F_w + F_o$, recognises that f_o will normally be retuned in sympathy with f_w.)

Thus, knowing the protection ratio required at a given value of f_b, (from Fig. 5), the relative protection required at various combinations of the ingredient frequencies may be assessed. But, before a useful result is revealed, the relationship between the ingredient amplitudes a_w a_u a_o and that of the beat-frequency resultant a_b must be established. These relationships are best expressed in logarithmic form so as to be independent of the system gain and give a ratio of levels in decibels. Thus the partial differential coefficients for amplitude may be written

$$\frac{a_o}{a_b}\,\frac{\partial a_b}{\partial a_o} = A_o \qquad \frac{a_w}{a_b}\,\frac{\partial a_b}{\partial a_w} = A_w \qquad \frac{a_u}{a_b}\,\frac{\partial a_b}{\partial a_u} = A_u$$

These amplitude coefficients may be derived from the same expressions as were the frequency coefficients F but greater care is required owing to some instrumental features. These are as follows.

First, the action of the mixer effectively limits the amplitude a_o making $A_o = 0$. Second, the a.g.c. action tends to make i.f. harmonic production independent of signal level in mechanism A. Third, and most subtly, the independence of the wanted and unwanted responses may lead to cancellations of coefficients when the wanted signal is involved in the interference mechanism. With these features in mind, it is possible to make a useful observation from a simplified theory.

11.2. A simplified treatment of intermodulation

In a general theory of intermodulation between a number of signals S, a particular product will be generated by one or more terms of the same frequency in the expansion of the multinominal expression

$$\sum E_n (S_1 + S_2 + S_3 \ldots S_m)^n$$

$$\text{where } S_r = a_r \cos(2\pi f_r t + \phi_r)$$

For the present purpose, it will be sufficient to consider only a trinomial expansion:

$$\sum_{n=1}^{\infty} E_n \sum_{i+j+k=n} n!\,\frac{S_o{}^i\,S_u{}^j\,S_w{}^k}{i!\;\;j!\;\;k!}$$

and, if we make the assumption that the product of a particular mechanism (determined by i, j and k) is determined only by that member of the series that has the appropriate frequency and the lowest power of n, then we may ignore the phase ϕ_r and express it as

$$V_p = a_p \cos 2\pi f_p t$$

$$= E_n\, n!\,\frac{a_o{}^i\,a_u{}^j\,a_w{}^k}{i!\;\;j!\;\;k!} \cos 2\pi(\pm i f_o \pm j f_u \pm k f_w)t$$

from which we may obtain the relations

$$\frac{a_o}{a_p}\,\frac{\partial a_p}{\partial a_o} = \left|\frac{\partial f_p}{\partial f_o}\right| = i_p$$

$$\frac{a_u}{a_p}\,\frac{\partial a_p}{\partial a_u} = \left|\frac{\partial f_p}{\partial f_u}\right| = j_p$$

$$\frac{a_w}{a_p}\,\frac{\partial a_p}{\partial a_w} = \left|\frac{\partial f_p}{\partial f_w}\right| = k_p$$

The importance of this result is that, for any one mechanism alone, the frequency and amplitude differential coefficients have the same modulus. The validity of the assumption has been tested by making level changes in typical interference conditions; the above relationship was verified to within ±15% for several mechanisms. Knowing the frequency coefficient, therefore, the amplitude coefficient is also known.

However, where two intermodulation processes are involved, as in the production of an interference beat of frequency f_b and relative amplitude a_b, then the interfering components must be treated separately and their coefficients then summed to find the effective differential amplitude coefficient A.

Thus, where the resultant beat arises from two signals near f_i, say a wanted signal f_p and an interference f_q, the coefficients of f_p are simply

$$\frac{\partial f_p}{\partial f_o} = 1, \quad \frac{\partial f_p}{\partial f_u} = 0, \quad \frac{\partial f_p}{\partial f_w} = -1, \quad i_p = k_p = 1$$

and those of f_q alone, by subtraction from the totals given in Table 1, must be

$$\frac{\partial f_q}{\partial f_o} = F_o - 1, \quad \frac{\partial f_q}{\partial f_u} = F_u, \quad \frac{\partial f_q}{\partial f_w} = F_w + 1$$

whence it follows that the required amplitude coefficients are

$$A_u = |F_u| \text{ and } A_w = |F_w + 1| - 1$$

In this way the coefficients shown in Table 3 may be calculated.

12. Appendix II

An exponential approximation to the CCIR protection ratio curve

A simple exponential approximation to the curve of relative protection ratio given in CCIR Recommendation 449-2 Curve B is given by

$$A_{rel} = -70[1 - \exp(-f_b/3)]\,[1 - 1{\cdot}6\exp(-f_b/10)]$$

The expression is fairly simple to express in terms of instructions in a computer program. The degree of approximation may be judged from the comparison of Fig. 12.

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